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VOICED ASPIRATED CONSONANTS

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Voiced aspirated consonants occur in a number of languages but there has been considerable confusion in their description. This paper is motivated in part by the need to improve upon the treatment in Ladefoged's widely used textbook A Course in Phonetics (1975) and in part to bring to the attention of linguists some recent experimental data which has not received wide notice. We will also present some pertinent preliminary results from our own study of Maithili,[1] an Indic language spoken in Nepal and India.

Traditionally, Indic languages have been described as having a series of stops which can be voiced or voiceless, aspirated or unaspirated. This description produces the symmetrical matrix in Figure 1. Ladefoged chose

	Unaspirated	Aspirated
Voiceless	p t ṭ etc.	pʰ tʰ ṭʰ etc.
Voiced	b d ḍ etc.	bʰ dʰ ḍʰ etc.

Figure 1

to use a feature of voice onset time to distinguish voiced, voiceless unaspirated and voiceless aspirated; and to use phonation types (voice and murmur) to distinguish voiced unaspirated from voiced aspirated. The Indic stop categories would then be represented as in the matrix in Figure 2. Ladefoged's analysis not only produces this asymmetrical and counterintuitive

Voice Onset Time

	Before Release	At Release	Delayed
Normal Voice	b d ḍ etc.	p t ṭ etc.	pʰ tʰ ṭʰ etc.
Murmur	b̤ʱ d̤ʱ ḍ̤ʱ etc.		

Figure 2

schema but it creates problems with the description of such sound changes as Grassman's Law (as pointed out by Halle [1973]).

Ladefoged was probably influenced in his treatment by the work of Lisker and Abramson (1964), who demonstrated that three categories of initial homorganic stops could be distinguished on the basis of voice onset time in a variety of languages. Because Lisker and Abramson regard all vibrations of the vocal cords as voicing, voice onset time did not distinguish voiced aspirated from voiced unaspirated. They suggest that (p.403)

> voiced aspirates are distinguished from the other voiced category by the presence of low amplitude buzz mixed with noise in the interval following the release of the stop.

Catford (1977:113) has suggested that voice onset time can be used for the voiced aspirates as well if it is redefined as

> delayed onset of normal voicing: the fact is that in such sounds as [bh] there is whispery voice rather than voice during the stop and for a certain period after its release. Just as with voiceless aspirated stops, there is thus a delay in the onset of normal voice.

Other descriptions of aspiration have also been used. For example, aspiration is frequently called a 'puff of air.' Ladefoged (1976:162) in a recent article on Igbo speculated that

> a better solution might be to revert to an older phonetic tradition, and define aspiration in terms of the rate of airflow.

Indeed, there is normally a greater airflow for aspirated sounds than unaspirated, as, for example, shown by Nihalani (1975a) for Sindhi. However, Kim (1965) found greater airflow for the Korean voiceless tense stops (which are never considered aspirated) than for the voiceless slightly aspirated stops. Greater airflow alone, then, is not a sufficient condition for aspiration.

Aspiration has also been attributed to greater subglottal air-pressure (for example, by Chomsky and Halle 1968:326). However, Ohala and Ohala (1972) have shown that in Hindi aspiration is not always accompanied by increased subglottal pressure. The same inconsistency can be seen in Nihalani's (1974) data for Sindhi.

Kim (1970) attributes aspiration to the size of the glottal opening. He noted that in Korean the glottal width at the time of the articulatory release was much greater for aspirated than for non-aspirated stops.[2] A fiberoptic study of Korean by Kagaya confirms Kim's earlier description based on cineradiography. Kim states (p. 112)

> what is controlled by the laryngeal muscles in the case of aspiration is not the timing of the glottal closing (Lisker and Abramson's view) but the size of the glottal opening.

According to Kim, the voicing lag observed by Lisker and Abramson is caused by the fact that it takes longer to close a wide glottis than a narrow one.

Because he was investigating Korean, which has only voiceless stops, Kim did not address his attention to the voiced aspirates.

If we accept Kim's definition without further modification, we find ourselves once again faced with the dilemma of the voiced aspirates since the vocal cords cannot simultaneously be widely abducted and vibrating.

It seems obvious that attention must be directed to the mode of vibration for voiced aspirates. Ladefoged calls this murmur and describes it as occurring (1975:122-123)

> when the vocal cords are only slightly apart; they can still vibrate, but at the same time a great deal of air passes through the glottis. Murmured sounds are sometimes made . . . with the glottis fairly open at one end. They can also be made with a narrower opening extending over nearly the whole length of the vocal cords.

Thanks to the development of fiberoptics it is now possible to observe and film the vocal cords during connected speech and thus see exactly what is happening during the production of aspirated sounds. This is done by inserting optic fibers through the nose and positioning them directly above the larynx. Although the light source through the fiber is not sufficient to allow for very high speed filming which would permit observation of individual vibrations of the vocal cords, it is possible using film at 50 or 60 frames per second to see the overall configuration of the glottis and note changes in width.

Let us first look at findings from a fiberoptic study of Hindi by Kagaya and Hirose (1975). Figure 3 displays typical glottal openings for intervocalic [p p^h b^h] and [t t^h d^h]. Time is represented by frames on the horizontal axis (50 frames per second) and glottal width is shown on an arbitrary scale on the vertical axis. R indicates the moment of

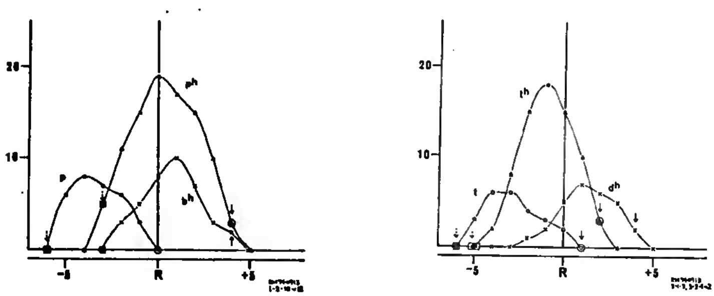

Figure 3. Typical glottal width contours for intervocalic [p p^h b^h] and [t t^h d^h] in Hindi. (Kagaya and Hirose 1975)

articulatory release. Note that the glottis opens much wider for the voiceless aspirated [pʰ] than it does for the unaspirated [p]. The same difference can be observed between [t] and [tʰ]. Figure 4 shows similar curves from our own study of Maithili filmed at 60 frames per second.

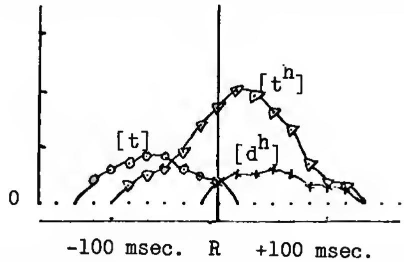

Figure 4. Typical glottal width contours for intervocalic [t tʰ dʰ] in the Maithili words [itir itʰik idʰia].

A worrisome problem for those espousing the voice onset time proposal has been how to deal with the aspirated and unaspirated distinctions in final position which can clearly be differentiated by Hindi listeners (Ahmed and Agrawal 1969, Bhatia 1976). Since there is no voicing following these stops, voice onset criteria cannot strictly be applied, although Abramson (1976:108) suggests that it would be possible to

> argue reasonably that word-final aspiration is an instance of voice onset time . . . To produce aspiration in final position, it is necessary to release the stop, thus articulating an unstressed additional syllable (or perhaps "pseudosyllable").

Kagaya and Hirose did not include final stops in their study of Hindi. Our data for Maithili, in which aspiration is also phonemic finally, do include some final stops. Note in Figure 5 that just prior to the

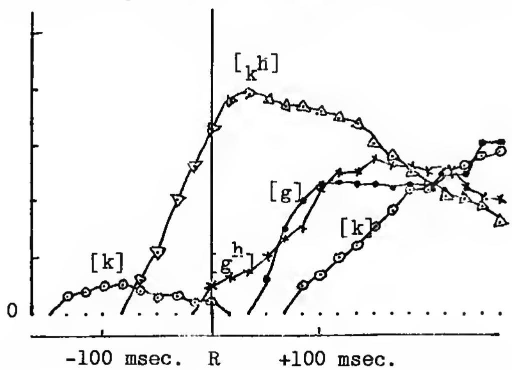

Figure 5. Typical glottal width contours for final [k kʰ g gʰ] in the Maithili words [bik bikʰ bag bagʰ].

release of a final aspirated stop, the glottis quickly opens widely. For the voiceless unaspirated stop, however, the glottis is narrow and in this token actually seems to close at the release. Clearly the critical factor for voiceless stops in final position is glottal width. Since there is no following gesture other than widening for respiration, the narrowed glottis of the unaspirated stop can only be attributed to the lack of aspiration. Because glottal width differences are also observable in other positions, width would seem to be a better characterization of aspiration than voice onset time, which is only sometimes applicable.

Now let us turn our attention to voiced stops. For unaspirated voiced stops, voicing continues through the word with no observable differences in glottal shape or vibrations. They are not shown in Figures 3 and 4 because the line representing their glottal width would be identical with the zero baseline. For the voiceless aspirates, the vocal cords remain adducted with no observable differences in vibrations until just before the release. At that point an opening occurs in the posterior part of the glottis while the anterior portion remains adducted and continues to vibrate. Occasionally a narrow opening extends the full length of the glottis. Note the glottal width for voiced aspirates in Figure 3. Kagaya and Hirose summarize their findings (p. 42):

> The voiced aspirated type is characterized by the closed glottis mostly during the articulatory closure period and by the open glottis immediately before and after the release.

Our Maithili data are virtually identical to the Hindi. Note in Figure 4 the opening for voiced aspirates beginning at the release. In Figure 5 glottal opening for the voiced aspirated stop begins earlier than for the voiced stop; it remains narrow until approximately the point at which the glottis begins to open after the voiced stop and then widens rapidly.

From these data it is clear that glottal width is also the key factor for aspiration of voiced stops. A modification of the definition of aspiration as glottal width will enable us once again to include both types of aspiration in the same phonetic category: aspiration is greater glottal width than there would otherwise be for the corresponding voiced and voiceless consonants. This approach would be in agreement with the feature 'spread glottis' proposed by Halle and Stevens (1971).

Timing of the glottal widening is also important. Note in Figures 3 and 4 that greatest glottal width for aspirated stops is neither at the onset nor the midpoint of the stop, but occurs at or shortly after the time of the articulatory release. The same timing relationship holds not only for stops but also the other voiced consonants. See Figure 6 for the glottal openings for [r^h l^h n^h]. Since [r^h] is a flap, there is no sustained closure. The glottal opening is related to the flap itself.

Thus, the timing which is important to production of aspiration is not voice onset but moment of maximum glottal width. The voicing lag is a natural result of this timing. We believe that this aspect of timing is an integral part of the description of aspiration.

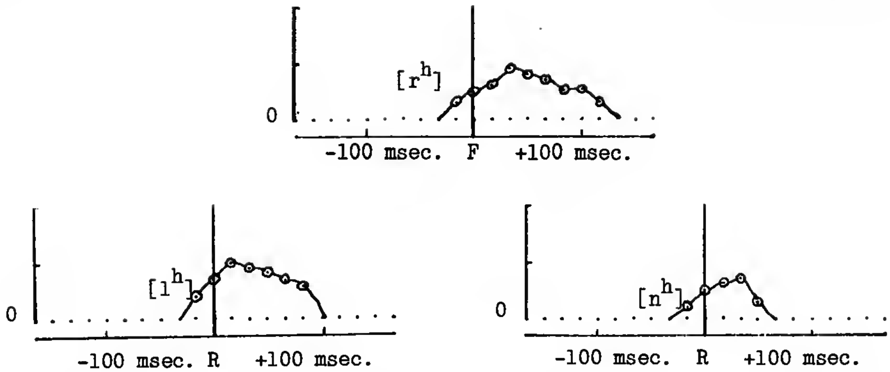

Figure 6. Typical glottal width contours for intervocalic [r^h l^h n^h] in the Maithili words [pir^hi pil^hi bin^hi].

In aspirated consonants we clearly have a sequence of events, or as Kagaya and Hirose (1975:43) put it based on their accompanying electromyographic data 'a sequence of two command units': consonant articulation followed by aspiration. This sequencing would lend the support of phonetic evidence to linguists who wish to analyze the aspirated consonants as a cluster of consonant plus [h].

Since both of these studies have been conducted on related Indic languages, there remains a question of how aspirates may be produced in other languages. Kagaya's study of Korean showed similar glottal timing for voiceless aspiration. For Owerri Igbo, Ladefoged (1976:168) concluded on the basis of oral pressure measurements that there must be murmur during the closure portion of the voiced aspirated stops to account for the greater mean oral pressure. Although he gives no evidence for the timing of the murmur, he later (p. 162) redefines aspiration as

> a period after the release of a stricture and before the start of regular voicing in which the vocal cords are farther apart than they are in regularly voiced sounds.

He no longer refers to these sounds as just murmured but 'murmured aspirated.'

Our evidence leads us to believe that voiced aspirated sounds are produced by a simple combination of vibrating vocal cords and aspiration, which in both voiced and voiceless sounds consists of glottal width and a timing factor locating the peak of the width near the consonant release.[3] There is no need -- at least for the languages so far examined -- to insist on the term 'murmur.' We can in good conscience speak about 'voiced aspirated' consonants.

NOTES

[1]We wish to thank the staff at Haskins Laboratories for providing us with the opportunity to make a fiberoptic study. We are especially grateful to Seiji Niimi and Thomas Baer for their assistance and advice. We also wish to thank John Michel of the University of Kansas for his help and the use of his facilities in the analysis of the films. The Maithili speaker was the second author of this paper.

[2]A hundred years ago in 1877, Henry Sweet, without the aid of sophisticated instrumentation, anticipated this finding. He claimed that in aspirated stops the glottis was left open during the stop while in unaspirated stops, the glottis was in the position for voice without any air being forced through. If we interpret this latter remark as narrowed glottis (rather than completely closed glottis as some phoneticians mistakenly believed) we have a remarkably accurate description of the states of the glottis in these sounds.

[3]Rothenberg (1968:101) states that "the mechanism involved is not in any real sense a conjunction of 'voicing' and 'aspiration'" but he does not elaborate on his reasons for this claim.

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